

PCT

WORLD INTELLECTUAL PROPERTY ORGANIZATION  
International Bureau



INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 5 :

B01D 53/36, B01J 29/14, 29/34

A1

(11) International Publication Number:

WO 93/04767

(43) International Publication Date:

18 March 1993 (18.03.93)

(21) International Application Number: PCT/EP92/01882

(22) International Filing Date: 18 August 1992 (18.08.92)

(30) Priority data:  
753,537 3 September 1991 (03.09.91) US

(71) Applicant (for CA only): FORD MOTOR COMPANY OF CANADA LTD. [CA/CA]; The Canadian Road, Oakville, Ontario L6J 5E4 (CA).

(71) Applicant (for DE only): FORD WERKE AG [DE/DE]; Werk Köln-Niehl, Henry Ford Strasse, Postfach 60 04 02, D-5000 Köln 60 (DE).

(71) Applicant (for FR MC only): FORD FRANCE S.A. [FR/FR]; B.O. 307, F-92506 Rueil-Malmaison Cédex (FR).

(71) Applicant (for GB only): FORD MOTOR COMPANY LIMITED [GB/GB]; Eagle Way, Brentwood, Essex CM13 3BW (GB).

(71) Applicant (for all designated States except CA DE FR GB MC): FORD MOTOR COMPANY [US/US]; County of Wayne, Dearborn, MI (US).

(72) Inventors: MONTREUIL, Clifford ; 201 Devonshire, Dearborn, MI 48124 (US). GANDHI, Haren, Sakarlal ; 38836 Creek-Bend Drive, Farmington Hills, MI 48331 (US). CHATTHA, Mohinder, Singh ; P.O. Box 2053, Dearborn, MI 48121 (US).

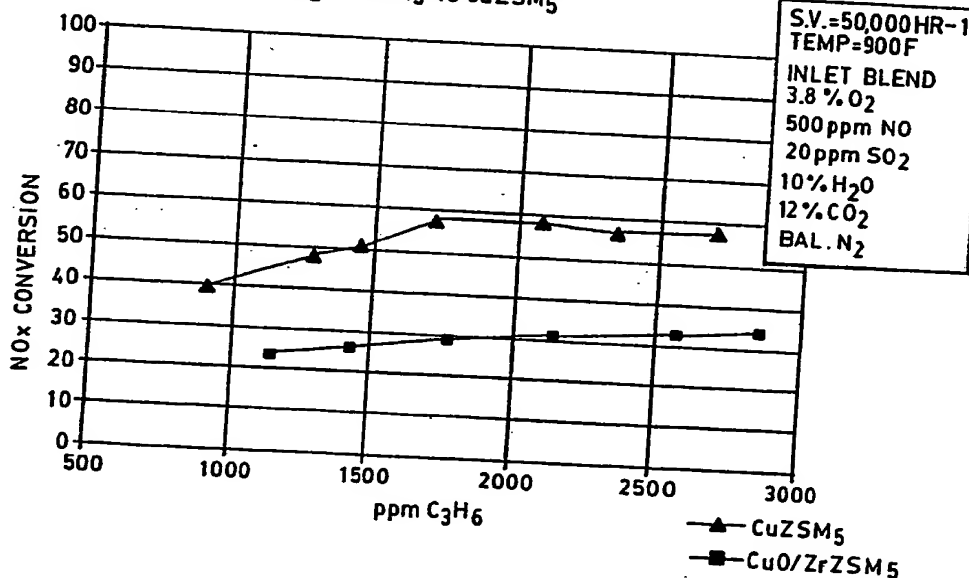
(74) Agent: MESSULAM, Alec, Moses; A. Messulam & Co., 24 Broadway, Leigh-on-Sea, Essex SS9 1BN (GB).

(81) Designated States: CA, JP, European patent (AT, BE, CH, DE, DK, ES, FR, GB, GR, IE, IT, LU, MC, NL, SE).

Published  
With international search report.

(54) Title: TWO-STAGE EXHAUST GAS CONVERSION CATALYST SYSTEM

COMPARISON OF NO<sub>x</sub> CONVERSION  
CuO/ZrO<sub>2</sub>/CuZSM<sub>5</sub> vs CuZSM<sub>5</sub>



(57) Abstract

This invention is directed to a two-stage catalyst system and a method of using the system for purification of exhaust gases containing nitrogen oxides, carbon monoxide and hydrocarbons. The exhaust gas may be automobile exhaust gas and invention is adapted to be useful in lean-burn situations, i.e. with oxygen rich environments. The system comprises as a first stage catalyst a combination of (i) refractory oxide impregnated with transition metal and (ii) transition metal-containing zeolite; and as a second stage catalyst an oxidative catalyst such as palladium on alumina.

**FOR THE PURPOSES OF INFORMATION ONLY**

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AT	Austria	FI	Finland	MN	Mongolia
AU	Australia	FR	France	MR	Mauritania
BB	Barbados	GA	Gabon	MW	Malawi
BE	Belgium	GB	United Kingdom	NL	Netherlands
BF	Burkina Faso	GN	Guinea	NO	Norway
BG	Bulgaria	GR	Greece	NZ	New Zealand
BJ	Benin	HU	Hungary	PL	Poland
BR	Brazil	IE	Ireland	PT	Portugal
CA	Canada	IT	Italy	RO	Romania
CF	Central African Republic	JP	Japan	RU	Russian Federation
CG	Congo	KP	Democratic People's Republic of Korea	SD	Sudan
CH	Switzerland	KR	Republic of Korea	SE	Sweden
CI	Côte d'Ivoire	LI	Liechtenstein	SK	Slovak Republic
CM	Cameroon	LK	Sri Lanka	SN	Senegal
CS	Czechoslovakia	LJ	Luxembourg	SU	Soviet Union
CZ	Czech Republic	MC	Monaco	TD	Chad
DE	Germany	MG	Madagascar	TG	Togo
DK	Denmark	ML	Mali	UA	Ukraine
ES	Spain			US	United States of America

## TWO-STAGE EXHAUST GAS CONVERSION CATALYST SYSTEM

This invention is directed to a two-stage exhaust gas conversion catalyst system comprising a first stage reducing catalyst and a second stage oxidative catalyst.

A number of catalysts have been suggested to convert automotive exhaust gas components like carbon monoxide, hydrocarbons, and nitrogen oxides into other gases. The nitrogen oxides present in the exhaust gas are nitric oxide (NO) and nitrogen dioxide (NO<sub>2</sub>), both generally referred to by the formula NO<sub>x</sub>. Present simultaneous control of the three components, nitrogen oxides, carbon monoxide and hydrocarbons, is by so-called "three-way" catalysts like platinum/rhodium and palladium/rhodium. These catalysts operate properly when the fuel mixture of a gasoline engine is slightly "rich" and the environment is a reducing atmosphere, i.e., in a narrow A/F ratio range between about 14.7 and 14.4. Such three-way catalysts are less than efficient in the reduction of NO<sub>x</sub> when engines are operated on the lean side where the A/F ratio is greater than 14.7. It is desirable, however, to operate engines on the lean side to realise a benefit in fuel economy, estimated to be in the range of 5-7%.

U.S. patent 4,297,328 discloses a copper-containing high-silica zeolite described as being useful as a three-way catalyst to reduce preferentially oxides of nitrogen to N<sub>2</sub> on the "lean" side of the A/F mixture. High-silica zeolites are described as those preferably above 20.

Copper-containing zeolites are prone to degradation at the high temperatures found in automobile exhaust systems. That is, the copper tends to react with the alumina of the zeolite and form copper aluminate which is a low surface area compound with reduced catalytic activity.

The invention overcomes problems associated with prior art catalysts and is directed to a two-stage exhaust gas conversion catalyst system for purification of exhaust

gases containing nitrogen oxides, carbon monoxide and hydrocarbons. The exhaust gas may be automobile exhaust gas and the invention is adapted to be useful in lean-burn situations, i.e., with oxygen rich environments. The system comprises a first stage catalyst and a second stage catalyst. The first stage catalyst is a combination of (i) refractory oxide impregnated with transition metal (ii) and transition metal-containing zeolite. The refractory oxide is selected from the group consisting essentially of zirconia, silica, titania and lanthana. The second stage catalyst is an oxidizing catalyst such as a noble metal on alumina. The first stage catalyst combination may comprise an intimate mixture of refractory oxide impregnated with transition metal and transition metal-containing zeolite or a layer of refractory oxide impregnated with transition metal on transition metal-containing zeolite. A preferred transition metal in the present invention is copper and the preferred refractory oxide is zirconia. Each of the catalysts may be deposited on a substrate such as a honeycomb ceramic or metallic carrier or be provided in pelleted form.

The invention according to another aspect is directed to a method for the purification of exhaust gases which comprises sequentially exposing the two-stage exhaust gas catalyst system disclosed above to exhaust gases of a combustion system.

The invention will now be described further, by way of example, with reference to the accompanying drawings, in which :

Fig. 1 graphically shows a comparison of  $\text{NO}_x$  conversions to  $\text{N}_2$  over a wide range of hydrocarbon concentrations when using a conventional Cu-ZSM-5 monolithic catalyst as compared to a  $\text{CuO/ZrO}_2/\text{Cu-ZSM-5}$  monolithic catalyst according to an embodiment of the present invention.

- 3 -

Fig. 2 graphically shows a comparison of hydrocarbon conversions over a wide range of hydrocarbon concentrations when comparing the catalysts of Fig. 1.

Fig. 3 illustrates the effect of a conventional oxidative catalyst placed in series (downstream) with a CuO/ZrO<sub>2</sub>/Cu-ZSM-5 according to an embodiment of the present invention.

The invention is directed to a two-stage catalyst system for the purification of exhaust gases containing nitrogen oxides, carbon monoxide and hydrocarbons. The first stage catalyst is placed close to the engine manifold, and converts NO<sub>x</sub> to N<sub>2</sub> through a reduction reaction with hydrocarbons present in the exhaust gas stream. It also converts the majority of hydrocarbons present to carbon dioxide and water and a portion of hydrogen to water. Partial conversion of carbon monoxide into carbon dioxide also occurs. The exhaust gases then pass through a second stage catalyst which further oxidizes any reducing species present.

The first stage catalyst comprises a combination of two materials, refractory oxide impregnated with transition metal and transition metal-containing zeolite. This combination may be in the form of an intimate mixture of the two materials or in the form of a layer of one material carrying a layer of the other, preferably a layer of refractory oxide impregnated with transition metal on top of transition metal-containing zeolite present on a substrate. Generally, the two materials of the first stage catalyst are employed in a ratio between about 10% to 90% and 90% to 10% by weight. Preferably, they are employed in a weight ratio between about 40% to 60% and 60% to 40% by weight.

The refractory oxide on which the transition metal is impregnated is selected from the group consisting essentially of zirconia (ZrO<sub>2</sub>), silica (SiO<sub>2</sub>), titania (TiO<sub>2</sub>), and lanthana (La<sub>2</sub>O<sub>3</sub>), with zirconia being preferred. The refractory oxid also may comprise compatible mixtures of thes oxides. The transition metal comprises, but is not

limited to, Cu, Co, Ni, Cr, Fe, Mn and compatible mixtures thereof. Transition metal is meant herein to include elemental metal as well as metal oxide. The transition metal present in the two materials of the first stage catalyst, e.g., in the refractory oxide impregnated with transition metal and the transition metal-containing zeolite may be independently selected from transition metals, i.e., one may be copper and the other be chromium. Preferably, the same transition metal or mixture of transition metals is employed in both materials. Most preferably this transition metal is copper. Optionally, but preferably, alumina is included along with the transition metal impregnated refractory oxide as a binder in amounts up to about 35% by weight based on the total weight of the alumina and the transition metal impregnated refractory oxide. According to the present invention, transition metal is not impregnated on the alumina because of its detrimental effect.

The refractory oxide impregnated with transition metal can be made by various techniques as will be apparent to one skilled in the art in view of the present disclosure. Such techniques will be discussed hereinafter with specificity to copper-containing zirconia but such techniques apply generally to other transition metal embodiments according to the present invention.

According to one method of making a copper-containing zirconia, a quantity of zirconia is soaked, repeatedly if desired, in a solution of a copper compound, subsequently dried, and then calcined at an elevated temperature between, e.g., 300-900°C, often at about 600°C. If alumina is to be incorporated as a binder, it would be mixed with the copper impregnated zirconia in a slurry prior to being applied as a separate layer or being combined with the transition metal-containing zeolite. The transition metal compound, in this embodiment being copper, would be one that is soluble or can be dispersed in a liquid. Particularly useful copper compounds are those which are soluble in an aqueous solution or which can be solubilized therein, e.g., with the aid of an acid or base. Exemplary

of such copper compounds are copper salts like copper nitrate and copper sulfate; organo-copper compounds like carboxylates of copper, copper acetate and copper (cupric) amines; organo-complexes of copper like diammine copper acetate; tetraamine copper sulfate, and copper acetylacetonate. Exemplary other transition metal compounds include cobaltous acetate, nickel acetate, ferric chloride, chromic nitrate and manganese acetate. Still other transition metal compounds useful in this invention to form the refractory oxide impregnated with transition metal will be apparent to those skilled in the art in view of the present disclosure.

If the calcining is carried out in air, the copper compound decomposes and forms copper oxide. If, on the other hand, the calcining is carried out in a reducing atmosphere the copper compound may be reduced to elemental copper. Preferably, the transition metal, in this embodiment being copper, is present in an amount between about 0.1 and 20% by weight in the copper-containing zirconia. When the first stage catalyst is placed in use, oxygen present in the exhaust gas will oxidize the copper to copper oxide.

In addition to the refractory oxide impregnated with transition metal, the first stage catalyst comprises a second material, transition metal-containing zeolite. The zeolite are selected from high silica zeolites having a  $\text{SiO}_2/\text{Al}_2\text{O}_3$  molar ratio which exceeds about 10 and preferably about 20. Representative of such high-silica zeolites are "silicalite", ZSM-5, ZSM-8, and ZSM-11. Examples of such zeolites and methods of making are disclosed in U.S. patent 4,297,328 to Ritscher et al which is hereby expressly incorporated by reference for such teachings. It is to be understood that other zeolites having the properties described herein may be used without departing from the scope of the present invention. Silicalite is a novel crystalline silica composition having a hydrophobic/organophilic characteristic which permits its use for selectively adsorbing organic materials preferentially to

- 6 -

water. Silicalite is more completely described in U.S. patent 4,061,724 which is hereby expressly incorporated by reference for such teachings. A zeolite in the protonated (acid form) may also be used. The diameter of the zeolite particle is not limited to any particular size. Smaller particle sizes are preferred as providing more uniform coatings on the catalyst support than those of larger particle size.

The transition metal such as copper is provided into the zeolite by ion exchange. Generally a sodium zeolite is contacted by an aqueous solution of another cation, in this case an aqueous solution of a soluble copper compound such as copper acetate wherein replacement of the sodium ion by copper ion takes place. It is advantageous to provide as much transition metal ion in the zeolite as possible since the amount of transition metal present in the zeolite is directly related to the catalytic activity of the first stage catalyst. After replacing the sodium ion with metal ion, the zeolite is generally washed to remove excess surface transition metal compound. It is not necessary to do so, however.

The first stage catalyst may be made by grinding each of the copper-containing zirconia and the copper-containing zeolite to a fine powder, mixing them together, forming a slurry of them and then applying the slurry to a substrate such as metal or ceramic honeycomb. While it is preferable to make the first stage catalyst this way, according to another embodiment it may be made by layering one material onto the other. For example, a layer of the copper-containing zeolite may be applied to the substrate and then a layer of copper-containing zeolite may be applied on top of the copper-containing zirconia layer. Binders may also be incorporated in forming the first stage catalyst, including the alumina discussed herein.

It has been found that while copper-containing zeolite displays three-way catalyst activity, the copper has a tendency with use to react detrimentally with the alumina at high temperatures. As a result of this reaction copper



aluminate is formed which is a low surface area compound with reduced catalytic activity. No similar detrimental reaction takes place with the refractory oxides such as zirconia employed according to the present invention. It is thus believed that by employing copper-containing zirconia in addition to copper-containing zeolite, additional copper is present in the first stage catalyst which is available to act catalytically and will not detrimentally react with the alumina. This insures that the copper remains in a form that is catalytically active.

Fig. 1 gives a comparison between the reduction of nitric oxide by a  $\text{CuO/ZrO}_2/\text{Cu-ZSM-5}$  catalyst (at a 33% by weight loading) according to an embodiment of the present invention and the reduction of nitric oxide by  $\text{Cu-ZSM-5}$  catalyst (also at a 33% by weight loading), both taken over a wide hydrocarbon concentration range. Conditions between the two runs are identical. A space velocity (S.V.) of  $50,000\text{hr}^{-1}$  (space velocity being defined as the volume of gas over the volume of catalyst per time) and a temperature of  $900^\circ\text{F}$  are used, typical of actual internal combustion engine exhaust gas compositions. The gas composition is described in the graph. As is evident, the reduction of nitric oxide by the  $\text{CuO/ZrO}_2/\text{Cu-ZSM-5}$  catalyst is more efficient than that by the  $\text{Cu-ZSM-5}$  catalyst over the entire range of hydrocarbon concentrations examined. The  $\text{CuO/ZrO}_2/\text{Cu-ZSM-5}$  catalyst reaction is on the average a factor of 2 more efficient than the comparable  $\text{Cu-ZSM-5}$  reaction.

Fig. 2 gives a comparison between the oxidation of hydrocarbon (propylene) by a  $\text{CuO/ZrO}_2/\text{Cu-ZSM-5}$  catalyst and the oxidation of hydrocarbon by a  $\text{Cu-ZSM-5}$  catalyst under the same conditions as in Fig. 1. The oxidation of hydrocarbon by the such  $\text{CuO/ZrO}_2/\text{Cu-ZSM-5}$  catalyst is more efficient than that of the  $\text{Cu-ZSM-5}$  catalyst. The  $\text{CuO/ZrO}_2/\text{Cu-ZSM-5}$  reaction is on the average a factor of  $2/3$  more efficient than the comparable  $\text{Cu-ZSM-5}$  reaction, yielding essentially quantitative conversion of hydrocarbon over the entire concentration range examined.

The second stage catalyst according to the present invention comprises a conventional oxidative catalyst such as palladium on alumina which further oxidizes any reducing species present, resulting in near quantitative conversion of hydrocarbons, carbon monoxide and hydrogen. While palladium on alumina is preferred for this second stage, it is not meant to be so limited. This second stage may comprise other oxidative catalysts like Pt/Al<sub>2</sub>O<sub>3</sub>, Pd/Al<sub>2</sub>O<sub>3</sub>, Pt/Rh/Al<sub>2</sub>O<sub>3</sub>, and Pd/Pt/Al<sub>2</sub>O<sub>3</sub>. While not as preferred as the above, the second stage catalyst may comprise zeolite in place of the alumina. The metal may be provided on the zeolite by ion-exchange and/or impregnation as will be apparent to one skilled in the art in view of the present disclosure.

15

#### Test Procedure

The catalysts are characterized in a quartz steady-state flow reactor. Gases are blended in a manifold by means of mass-flow controllers, routed through a by-pass line to an analytical train for analysis, and then routed over the catalyst. The post-catalyst gases are then analysed to determine the extent of reaction of the various constituents. The catalyst used is in the form of a cylindrical ceramic monolith measuring 1 inch in diameter by 1.5 inches long. Total gas flow over the catalyst is 16.09 liters/min. which gives a space velocity of 50,000 hr<sup>-1</sup>. An inlet temperature of 900°F is used in all tests. The composition of the gas stream used in the following examples is that shown in Fig. 3.

30

#### Example 1

(a) Copper acetate monohydrate (7.8 g) is dissolved in 150 ml of acetic acid/water mixture (50:50). Zirconia, 50 g, is placed in a beaker and is impregnated with the copper acetate solution by incipient wetness technique. It takes three impregnations to finish all the

35

- 9 -

solution. The impregnated material is dried at 120°C between impregnations and after the final impregnation. It is then calcined at 600°C for four hours.

(b) Cu-ZSM-5, which contains 3% by weight ion-exchanged copper, is obtained from Universal Oil Products (UOP). This material is in a powder form suitable for direct use.

(c) A mixture of equal weight amounts of materials (a) and (b) above is ball-milled in a sufficient amount of water to make a fine slurry. The slurry is applied to a cordierite monolith in several steps to obtain 33% loading of this mixture on the monolith as a % of the aggregate weight. The final drying is carried out at 120°C for three hours and the calcination is carried out at 600°C for four hours to form the first stage catalyst.

The first stage catalyst prepared above is coupled with a 1% Pd/Al<sub>2</sub>O<sub>3</sub> conventional oxidative catalyst (as the second stage catalyst) to form a two stage catalyst system according to the present invention. The system is placed within a testing device with the second stage downstream of the first and tested according to the described test procedure. Fig. 3 gives a comparison of conversions of nitric oxide, hydrocarbon, carbon monoxide and hydrogen which is obtained with the two stage catalyst of the example as well as that of the first stage alone. As can be seen, the use of the second stage in addition to the first stage improves the oxidation of carbon monoxide and hydrogen and also hydrocarbon but to a lesser extent for hydrocarbon.

30

### Example 2

Zeolite ZSM-5 (UOP) is ion exchanged by stirring with a 0.05 M solution of copper acetate. The material is filtered, washed, and ion exchanged three times. It is then dried at 120°C for 3 hours and then calcined at 600°C for three hours. The product contains 2.0 % copper by weight.

A first stage catalyst is prepared according to the procedures in Example 1(c) using the Cu/ZrO<sub>2</sub> product

- 10 -

described in Example 1(a) and the material prepared in this example instead of that of 1(b). The catalyst is provided on a cordierite monolith according to the procedure of Example 1.

- 5           The first stage catalyst prepared in Example 2 is coupled with the conventional oxidative catalyst used in Example 1 immediately downstream to form a two stage catalyst system according to the present invention. Similar test procedures give results comparable to those of
- 10 Example 1 except that  $\text{NO}_x$  conversion decreases about 10% with the decreased copper loading in the zeolite.

### Example 3

- 15           A first stage catalyst is prepared as described in Example 1(c) from a 40:60 weight mixture of the materials described in Example 1(a) and 1(b).

- The first stage catalyst prepared in this example is provided on a cordierite monolith according to the
- 20 procedure of Example 1. It is coupled with a  $\text{Pt}/\text{Al}_2\text{O}_3$  conventional oxidative catalyst immediately downstream to form a two stage catalyst system according to the present invention. Test results are comparable to those of Example 1.

25

### Example 4

- A first stage catalyst is made according to the procedure of Example 1. Catalyst grade -alumina (Degussa
- 30 Corp.) in an amount of 25% by weight based on the total weight of alumina and copper impregnated zirconia is additionally included during slurry formation in the composition of Example 1(c) as a binder.

- The first stage catalyst prepared in this example
- 35 is provided on a cordierite monolith according to the procedure of Example 1. It is coupled with the conventional oxidative catalyst used in Example 1 immediately downstream to form a two stage catalyst system according to the present

- 11 -

invention. The initial efficiency of catalytic activity is the same as in Example 1, but deteriorates somewhat with time.

5

#### Example 5

Cu-ZSM-5, described in Example 1(b), is ball milled with sufficient water to form a fine slurry and then coated on a monolith to obtain 21% weight loading. The sample is subsequently coated with a Cu/ZrO<sub>2</sub> product (prepared as in Example 1(a)) from a water slurry thereof to impart a 11.5% coating by weight on the Cu-ZSM-5 layer. The monolith so prepared is calcined at 600°C for five hours to produce the first stage catalyst.

15

The first stage catalyst catalyst as prepared above is provided on a cordierite monolith. It is coupled with a 1% Pt/Al<sub>2</sub>O<sub>3</sub> conventional oxidative catalyst to form a two stage catalyst system according to the present invention. Testing gives results comparable to those of Example 1.

20

#### Example 6

Fifty grams of zeolite ZSM-8 (UOP) is ion-exchanged by stirring with a 0.01 M solution of nickel acetate. The material is filtered, washed and ion-exchanged three more times. It is then dried at 120°C and calcined at 600°C for three hours. The product contains 3.2% nickel by weight.

A first stage catalyst is prepared as described in Example 1(c) by employing the above material and the Cu/ZrO<sub>2</sub> product from Example 1(a) in equal amounts by weight.

30

The first stage catalyst catalyst prepared in this example is provided on a cordierite monolith according to the procedure of Example 1. It is coupled with a 1% Pd/Al<sub>2</sub>O<sub>3</sub> conventional oxidative catalyst. Test results are similar to those of Example 1 except that NO conversion is approximately 75% of that of Example 1.

35

- 12 -

## Example 7

5 Zirconia is impregnated with copper as described in Example 1(a) to deposit 7.5% copper by weight. This product is employed to prepare a catalyst product as described in Example 1 (c).

10 The first stage catalyst prepared in this example is provided on a cordierite monolith according to the procedure of Example 1. It is coupled with a 1% Pt/Al<sub>2</sub>O<sub>3</sub> conventional oxidative catalyst. Test results are similar to those of Example 1.

## Example 8

15 Fifty grams of silica are impregnated with 8.3 g of copper acetate as described in Example 1(a). A first stage catalyst is prepared from this Cu<sub>2</sub>SiO<sub>2</sub> product and Cu-ZSM-5 as described in Example 1(c).

20 It is coupled with a 1% Pd/Al<sub>2</sub>O<sub>3</sub> conventional oxidative catalyst. The test procedure as described in Example 1 shows the emission reductions comparable to those of Example 1.

25

## Example 9

30 Fifteen grams of titania and 35 grams of zirconia are mixed in a beaker and the mixture is impregnated with 8.1 grams of copper acetate as described in Example 1(a). A first stage catalyst is prepared following the procedure of Example 1(b) and (c). The second stage is prepared as in Example 1. Test results of the two-stage catalyst system are similar to those shown in Example 1.

35

## Example 10

Fifty grams of zirconia are soaked in a solution of 12 grams of lanthanum nitrate in 50 ml of water. The

- 13 -

material is dried at 125°C and then calcined at 450°C for five hours. This material is impregnated with 9.7 grams of copper acetate as described in Example 1(a). With the use of this Cu/La<sub>2</sub>O<sub>3</sub>/ZrO<sub>2</sub> material and Cu-ZSM-5, the first stage catalyst is obtained as described in Example 1. This first stage is combined with the second stage described in Example 1 and is subjected to testing. The results show that NO<sub>x</sub>, CO and hydrocarbon conversions are comparable to those seen in Example 1.

10

15

20

25

30

35

## CLAIMS

1. A two-stage exhaust gas conversion catalyst system  
for purification of exhaust gases containing nitrogen  
oxides, carbon monoxide and hydrocarbons which comprises:  
a combination of (i) refractory oxide impregnated  
with transition metal and (ii) transition metal-containing  
zeolite, as a first stage catalyst, said refractory oxide is  
selected from the group consisting essentially of zirconia,  
silica, titania, and lanthana; and  
oxidative catalyst, as a second stage catalyst,  
said exhaust gas being exposed to said second stage  
catalyst after being exposed to said first stage catalyst.
2. A system according to claim 1, wherein said  
transition metal of said refractory oxide impregnated with  
transition metal and said transition metal-containing  
zeolite are independently selected from the group of  
transition metal comprising copper, cobalt, nickel,  
chromium, iron, manganese and compatible mixtures thereof.
3. A system according to claim 1, wherein the  
transition metal is present in said refractory oxide  
impregnated with transition metal in an amount between about  
0.1 and 20 weight percent based on the weight of said  
refractory oxide impregnated with transition metal.
4. A system according to claim 1, wherein said  
combination comprises (i) said refractory oxide impregnated  
with transition metal and (ii) said transition metal-  
containing zeolite in a weight ratio between about 90% to  
10% and 10% to 90%.
5. A system according to claim 1, wherein said  
zeolite has a  $\text{SiO}_2/\text{Al}_2\text{O}_3$  molar ratio greater than 10.
6. A system according to claim 1, wherein said  
oxidative catalyst comprises a noble metal on alumina.



7. A system according to claim 1, wherein the first stage catalyst combination comprises an intimate mixture of said refractory oxide impregnated with transition metal and said transition metal-containing zeolite.

5 8. A system according to claim 1, wherein the first stage catalyst combination comprises a layer of said refractory oxide impregnated with transition metal adhered to a layer of said transition metal-containing zeolite.

10 9. A method for the conversion of exhaust gases containing nitrogen oxides, carbon monoxide and hydrocarbons which comprises sequentially exposing said first stage catalyst and said second catalyst as claimed in any one of  
15 the preceding claims.

10. A two-stage exhaust gas conversion catalyst system for purification of exhaust gases containing nitrogen oxides, carbon monoxide and hydrocarbons which comprises:

20 a combination of (i) zirconia impregnated with copper and (ii) copper-containing zeolite, as a first stage catalyst, said zeolite having a  $\text{SiO}_2/\text{Al}_2\text{O}_3$  molar ratio greater than 10; and  
25 oxidative catalyst, as a second stage catalyst, said exhaust gas being exposed to said second stage catalyst after being exposed to said first stage catalyst.

30

35

1 / 3

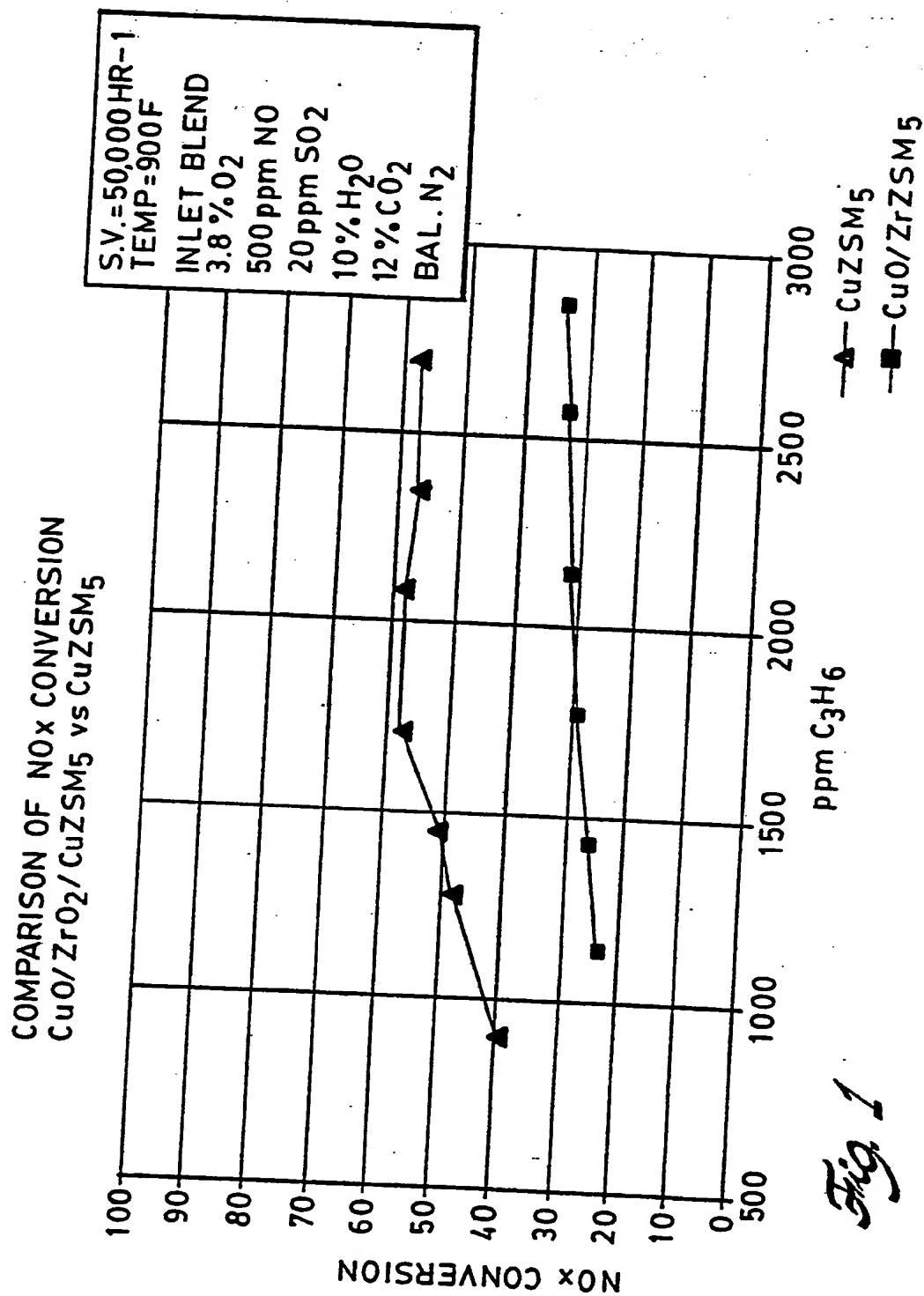


Fig. 1

2 / 3

# COMPARISON OF HYDROCARBON CONVERSION CuO/ZrO<sub>2</sub>/CuZSM5 vs CuZSM5

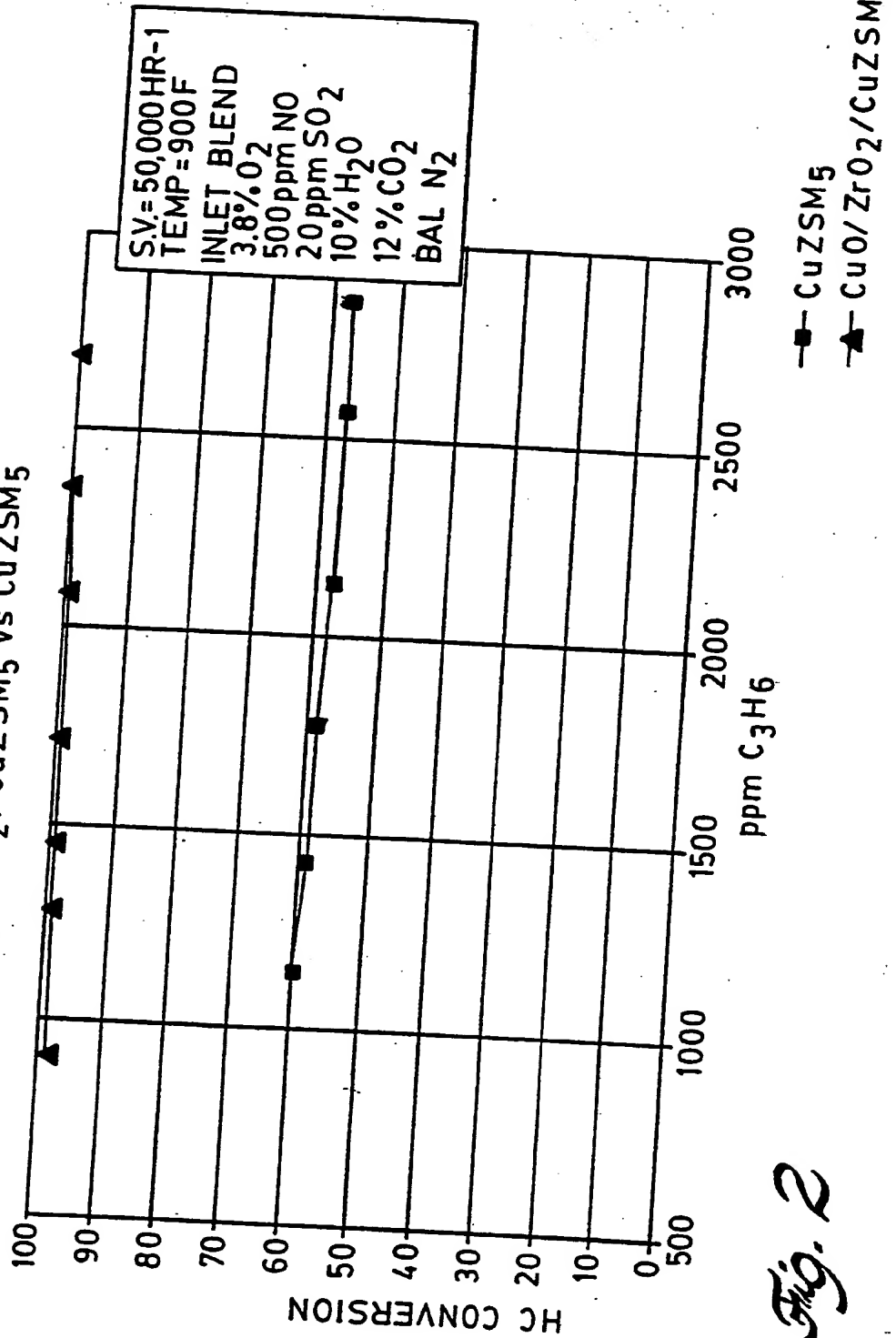
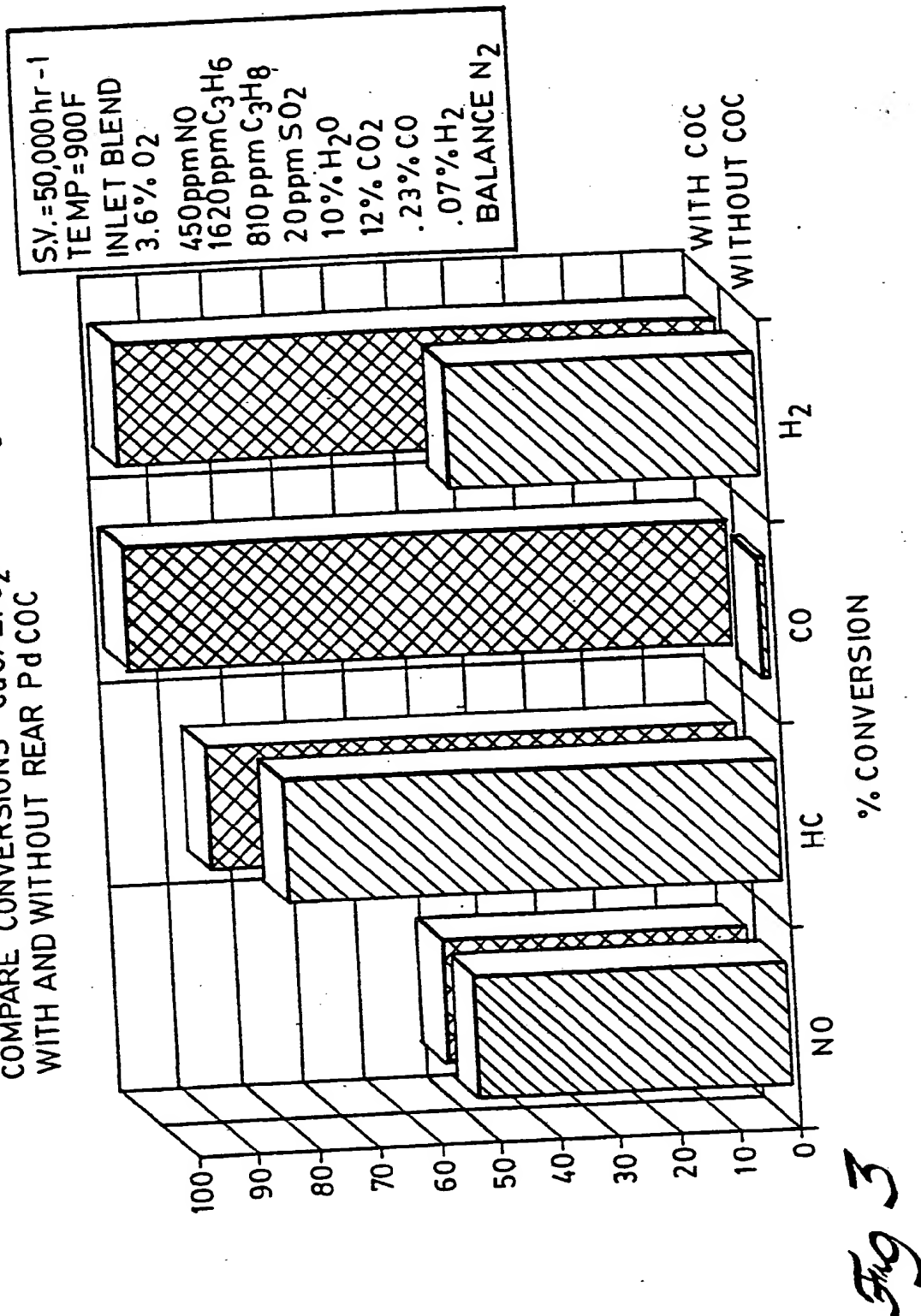


Fig. 2

3 / 3

COMPARE CONVERSIONS—CuO/ZrO<sub>2</sub>/CuZSM5  
WITH AND WITHOUT REAR Pd COC



# INTERNATIONAL SEARCH REPORT

International Application No PCT/EP 92/01882

<b>I. CLASSIFICATION F SUBJECT MATTER</b> (If several classification symbols apply, indicate all) <sup>6</sup> According to International Patent Classification (IPC) or to both National Classification and IPC IPC5: B 01 D 53/36, B 01 J 29/14, 29/34		
<b>II. FIELDS SEARCHED</b>		
Classification System		Minimum Documentation Searched <sup>7</sup> Classification Symbols
IPC5		B 01 D; B 01 J
Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in Fields Searched <sup>8</sup>		
<b>III. DOCUMENTS CONSIDERED TO BE RELEVANT<sup>9</sup></b>		
Category <sup>10</sup>	Citation of Document, <sup>11</sup> with indication, where appropriate, of the relevant passages <sup>12</sup>	Relevant to Claim No. <sup>13</sup>
X	EP, A2, 0365308 (BABCOCK-HITACHI KABUSHIKI KAISHA) 25 April 1990, see page 1, line 38 - line 45; page 2, line 4 - line 44	1-10
A	US, A, 4297328 (JAMES S. RITSCHER ET AL) 27 October 1981, see the whole document	1-10
A	EP, A2, 0393905 (ENGELHARD CORPORATION) 24 October 1990, see the whole document	1-10
<p> <sup>10</sup> Special categories of cited documents:  <sup>"A"</sup> document defining the general state of the art which is not considered to be of particular relevance  <sup>"E"</sup> earlier document but published on or after the international filing date  <sup>"L"</sup> document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)  <sup>"O"</sup> document referring to an oral disclosure, use, exhibition or other means  <sup>"P"</sup> document published prior to the international filing date but later than the priority date claimed  <sup>"T"</sup> later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention  <sup>"X"</sup> document of particular relevance, the claimed invention cannot be considered novel or cannot be considered to involve an inventive step  <sup>"Y"</sup> document of particular relevance, the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art  <sup>"Z"</sup> document member of the same patent family         </p>		
<b>IV. CERTIFICATION</b>		
Date of the Actual Completion of the International Search 2nd November 1992		Date of Mailing of this International Search Report 13 NOV 1992
International Searching Authority EUROPEAN PATENT OFFICE Form PCT/ISA/210 (second sheet) (January 1985)		Signature of Authorized Officer Britt-Marie Lundell

**ANNEX TO THE INTERNATIONAL SEARCH REPORT  
ON INTERNATIONAL PATENT APPLICATION NO. PCT/EP 92/01882**

SA 63549

This annex lists the patent family members relating to the patent documents cited in the above-mentioned international search report.  
The members are as contained in the European Patent Office EDP file on 30/09/92  
The European Patent office is in no way liable for these particulars which are merely given for the purpose of information.

Patent document cited in search report	Publication date	Patent family member(s)		Publication date
EP-A2- 0365308	25/04/90	CA-A-	2000906	18/04/90
		JP-A-	2107315	19/04/90
		US-A-	5047378	10/09/91
US-A- 4297328	27/10/81	NONE		
EP-A2- 0393905	24/10/90	CA-A-	2012039	20/10/90
		JP-A-	2293022	04/12/90
		US-A-	5024981	18/06/91

For more details about this annex : see Official Journal of the European patent Office, No. 12/82

EPO FORM P0479